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Technical Report

TECHNICAL EVALUATION OF DIVER-HELD POWER TOOLS

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TECHNICAL EVALUATION OF DIVER-HELD POWER TOOLS

Technical Report R-729

YF 38.535.003.01.002

by

S. A. Black and F. B. Barrett*

ABSTRACT

Pneumatic and hydraulic hand-held power tools were evaluated by divers performing realistic underwater tasks. These tasks included drilling steel and aluminum, nut running and tightening, grinding metal, and chain sawing wood. An on-the-site observer monitored diver performance time for each task. Diver skill in effective tool utilization is very important in working underwater. At test depths to 60 feet, hydraulic tools were very effective and practical, while pneumatic tools, although effective, required excessive maintenance. At greater depths, hydraulic tools retain their effectiveness, but pneumatic tools lose effectiveness because of the compressibility of gas. Hydraulic tools generally supply more energy per unit of tool weight than do pneumatic tools; thus, the diver can perform work more rapidly using hydraulic tools.

* Naval Missile Center, Point Mugu, California.

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Pneumatic and hydraulic hand-held power tools were evaluated by divers performing realistic underwater tasks. These tasks included drilling steel and aluminum, nut running and tightening, grinding metal, and chain sawing wood. An on-the-site observer monitored diver performance time for each task. Diver skill in effective tool utilization is very important in working underwater. At test depths to 60 feet, hydraulic tools were very effective and practical, while pneumatic tools, although effective, required excessive maintenance. At greater depths, hydraulic tools retain their effectiveness, but pneumatic tools lose effectiveness because of the compressibility of gas. Hydraulic tools generally supply more energy per unit of tool weight than do pneumatic tools; thus, the diver can perform work more rapidly using hydraulic tools.

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APPENDIXES

INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) has been engaged in the development and evaluation of underwater power tool systems for the past 3 years. The systems have included those intended for use by divers in construction, maintenance, repair, and salvage work. The objectives of the program were:

1. Determine the effectiveness of existing equipment.
2. Develop submersible and surface-operated tool power supply systems to fulfill known requirements.
3. Accomplish minor modifications of diver-operated power tools to improve tool effectiveness.
4. Recommend further tool modifications required for optimum effectiveness.

This report provides data on tool performance, diver performance, and maintenance for several hand-held underwater power tools. Pneumatic and hydraulic impact wrenches, a hydraulic chain saw, and a hydraulic grinder were tested. In some instances, modifications were made to the tools in advance of formal testing in order to enhance diver safety or to gain acceptable levels of tool performance.

The overall objective has been to obtain basic data on tool performance and related diver performance to serve as guide information for those responsible for planning operations requiring underwater power tools. The emphasis, therefore, has been on testing tools reasonably representative of their basic types rather than performing a comparative study of commercially available tools.

An extensive evaluation of pneumatic power tools has been accomplished and is included in an earlier report.* Although pneumatic tools are discussed herein, the major emphasis is on the evaluation of oil hydraulic tools. Pneumatic

* Naval Civil Engineering Laboratory. Technical Report R-653: Diver performance usir handtools and hand-held pneumatic tools, by F. B. Barrett and J. T. Quirk. Port Hueneme, Calif., Dec. 1969.

tools have proven to be depth limited, and their underwater use has resulted in excessive tool maintenance time and operating costs. Hydraulic tools, on the other hand, are affected only slightly by greater depth and are sealed against the environment; thus, maintenance time and costs are relatively low.

The tool evaluation was carried out concurrently with the evaluation of three independent tool power sources. During the evaluation, Navy-qualified divers performed realistic work tasks and their performance was monitored by a diver/observer. This type of combined evaluation permits the experimenter to obtain realistic information on both the mechanical systems and the diver/operators.

The three power sources are shown in Figures 1, 2, and 3. The first source, the cryogenic power module, utilizes liquefied nitrogen to generate gas under pressure to power penumatic tools. The second source, the electrohydraulic system, utilizes storage batteries to power an electric motor coupled to a hydraulic pump, which in turn supplies the oil hydraulic tools. Both of these systems are submersible and self-contained, thus requiring no direct surface support for diver use. The third source is a diesel hydraulic unit. This is a surface-supported system in which the hydraulic pump is driven by a diesel engine and hoses are used to convey the pressurized hydraulic oil to and from the tool in use underwater. Evaluation of the power modules is reported elsewhere.*

DESCRIPTION OF EQUIPMENT

Power Tools

One pneumatic tool and three hydraulic tools were used during the evaluation program. The pneumatic tool was a 1/2-inch square-drive impact wrench. Previous NCEL work on pneumatic tools proved that selection of pneumatic tools for use underwater must be based on simplicity of design and ease of maintenance. Seawater enters the motor section through the open exhaust, necessitating complete disassembly, cleaning, and oiling after each day of use. The tool selected (Figure 4) could be disassembled, cleaned, oiled, and reassembled in approximately 15 minutes.

* Naval Civil Engineering Laboratory. Technical Note: Submersible diver tool power sources—electrohydraulic and cryogenic pneumatic, by S. A. Black. Port Hueneme, Calif., (To be published.)

Figure 1. Cryogenic power module.

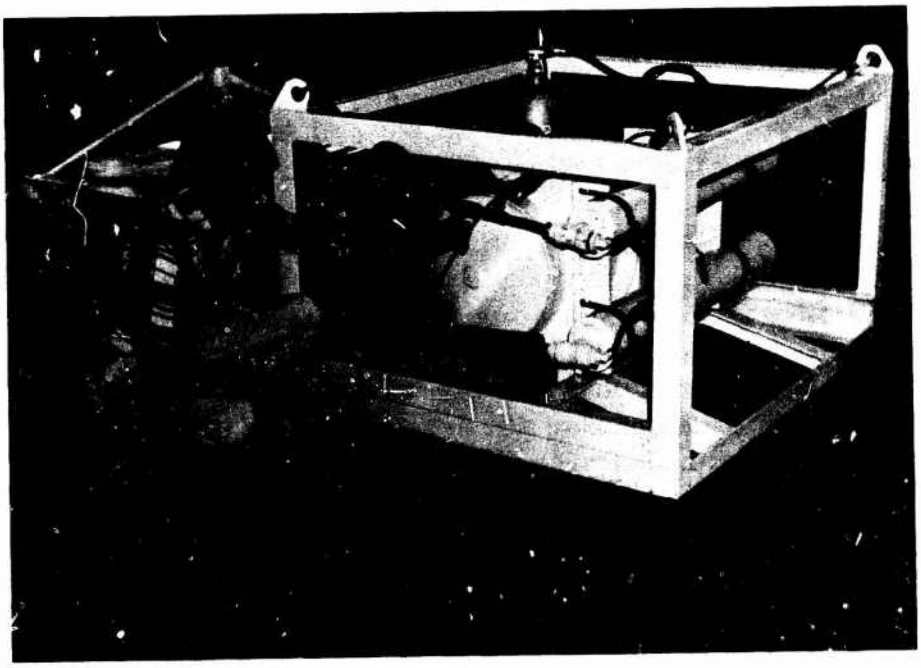

Figure 2. Electrohydraulic system.

Figure 3. Diesel hydraulic unit.

There are only a few companies which manufacture hydraulic tools suitable for diver use. Most of the tools available were designed for land construction and maintenance work and are excessively heavy and bulky. The three tools were selected on the basis of size, weight, and configuration. The tools, an impact wrench, a chain saw, and a grinder, are shown in Figures 5, 6, and 7; and the specifications are listed in Table 1.

Since hydraulic tools are sealed against the environment, they are less of a maintenance problem than are pneumatic tools. However, they do require limited post-dive maintenance, such as cleaning and lubricating exposed bearing surfaces and protecting exposed metal parts from corrosion.

Impact wrenches were used in place of drill motors for drilling operations, because they produce very little countertorque on the diver.

A more complete description of power tools and modifications is contained in Appendix A.

Table 1. Power Tool Specifications

Specification	Manufacturer Ratings
Pneumatic Impact Wrench	
Torque	130 ft-lb
Flow and pressure	11.5 cfm at 90 psig
No-load speed	7,200 rpm
Drive	1/2-in. square
Impact frequency	1,100 impacts/min
Weight	6 lb
Hydraulic Impact Wrench	
Basic type	Open/closed center
Chuck	5/8-in. quick-change hexagon drive
Maximum chuck speed	850 rpm
Maximum flow	6 gpm
Operating pressure	1,000-1,500 psig
Impact frequency	1,700 blows/min
Weight	10.5 lb
Bolt capacity	5/8-3/4 in.
Torque	250 ft-lb
Hydraulic Chain Saw	
Basic type	Open center
Cutting capacity	9-21 in.
Maximum flow	8 gpm
Chain speed	3,000-3,500 fpm
Operating pressure	1,000-2,000 psig
Weight	7 lb
Hydraulic Grinder	
Basic type	Open center
Power rating	4-6 hp
Maximum flow	6 gpm
Motor speed	455 rpm/gpm
Weight	14 lb
Maximum grind wheel diameter	7 in.

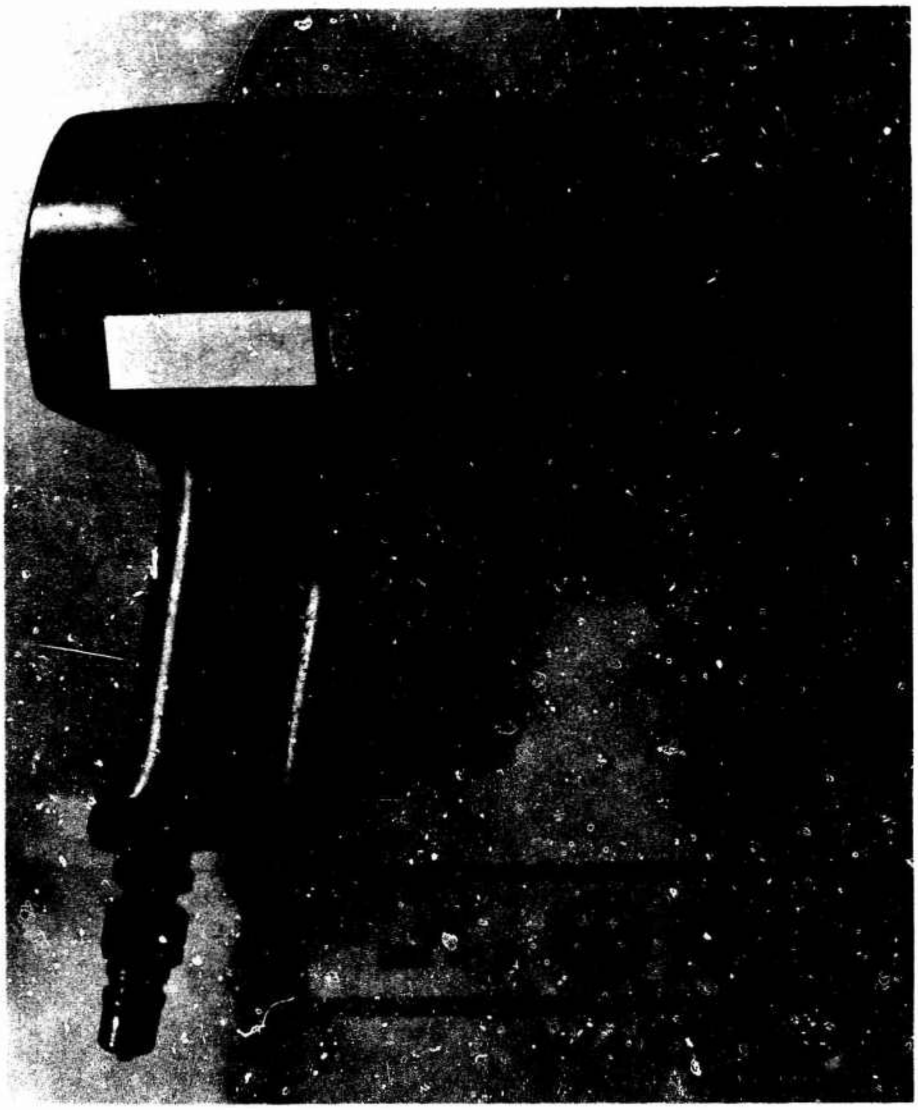

Figure 4. Pneumatic impact wrench.

Power Supply Hoses

The power transmission line provides the link between the power supply and the tool in the diver's hands. Pneumatic tools require one supply hose, whereas oil hydraulic systems require a supply hose and a return hose. Table 2 lists the hoses and related specifications used with each power source. Hoses should be selected to minimize the power transmission losses in the

line. Line losses are a function of (1) fluid flow, (2) hose diameter, and (3) restrictions at the couplings. Quick-connect couplings were used at the interface between the tools and the power transmission lines. Some trade-offs must be made between minimizing power loss and improving the ease with which the hoses can be handled by divers. For example, increasing hose diameter would result in less power loss, but the increase in weight and stiffness and the greater area exposed to underwater current could result in greater diver and tender handling problems.

METHODS

Test Sites and Environmental Conditions

The basic power tool tests were conducted in the harbor at Port Hueneme, California, for several reasons:

1. Shallow depths provide an adequate test of tool and diver performance for most operations.
2. The tests were much less costly and less dangerous to accomplish than if conducted at deep-ocean depths.
3. The logistics were simplified by the proximity of the diving locker and support facilities.
4. A small equipment building and a water-to-dock elevator were located at the water edge, eliminating the necessity for a diving equipment boat.

A high correlation between data obtained during tests conducted in a harbor (as were the majority of the tests reported herein) and tests conducted in the ocean can be expected. Statistical analysis of data obtained from similar diver performance tests conducted in the ocean and in a test tank revealed a rather high (0.81) correlation.* Harbor and ocean environmental conditions are even more closely related and, consequently, a higher correlation can be expected.

Limited tests were also conducted in the ocean to add validity to the shallower harbor tests and to determine if there were any problems unique to operations where a support boat was required. This also provided an opportunity to contrast diver performance using different types of diving gear. The environmental conditions are listed in Table 3.

* Barrett and Quirk, *op. cit.*

Table 2. Hose Specifications for Power Supplies

Power Source	Hose Function	Hose Specifications							
		Core	Braid	Cover	Inside Diameter (in.)	Outside Diameter (in.)	Weight (lb/ft)	Minimum Bending Radius (in.)	Working Pressure (psia)
Cryogenic pneumatic	supply	neoprene	rayon	neoprene	5/16	9/16	0.15	flexible	250
Electrohydraulic	supply and return	nylon	braided nylon fiber	polyurethane	1/2	25/32	0.12	3	4,000
Diesel hydraulic	supply	synthetic rubber	multiple wire and cotton	synthetic rubber	5/8	1-3/32	0.63	8	2,750
	tool whip[a]	synthetic rubber	single wire and cotton	synthetic rubber	13/32	49/64	0.26	4.6	2,000
	return	synthetic rubber	single wire and cotton	synthetic rubber	5/8	1-5/64	0.36	6.5	1,500

[a] The supply and return hoses were terminated approximately 10 feet from the tool, at which point more flexible and smaller hoses were used.

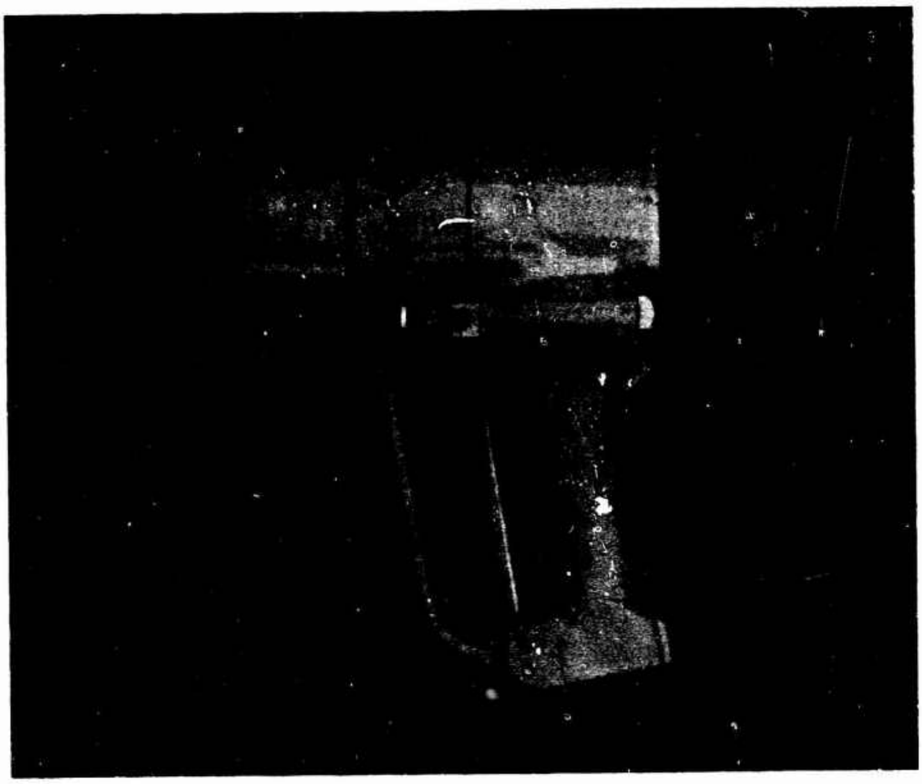

Figure 5. Hydraulic impact wrench.

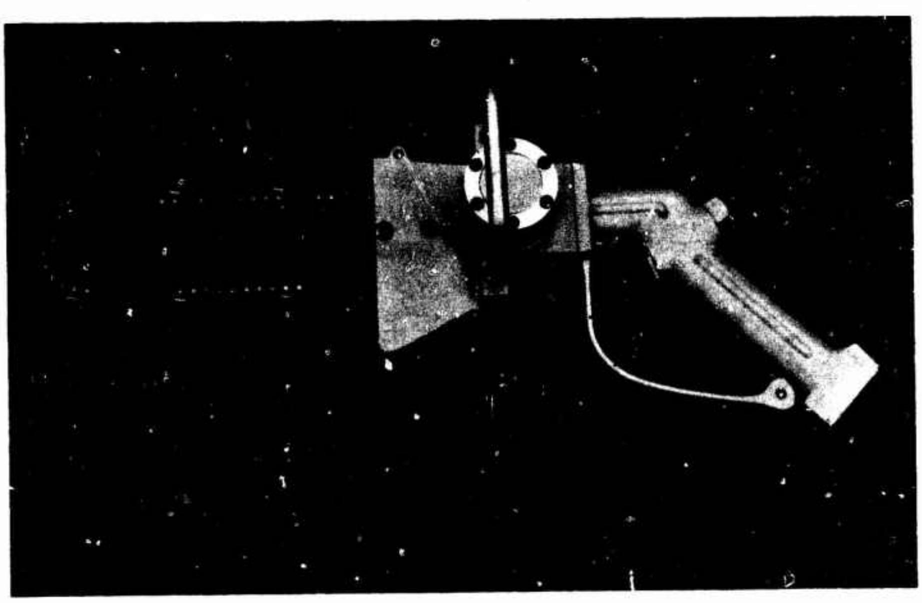

Figure 6. Hydraulic chain saw.

Table 3. Environmental Conditions at Test Sites

Condition	Ocean Tests	Harbor Tests
Depth	60 ft	20 ft
Water temperature	52^oF	$51\text{-}61^oF$
Visibility	20 ft	3-10 ft
Current	0-1 ft/min	0 ft/min
Wind velocity	15-25 knots	0-10 knots
Swell height	3-6 ft	0-1 ft

Test Equipment

A test stand was placed on the bottom of the harbor near the shore at a depth of approximately 20 feet. The test stand was designed to provide flat working surfaces with no handholds or footholds available. This was to simulate conditions such as might be encountered during salvage or construction operations. The stand provided test plate attachment surfaces for three basic diver working positions: vertical, overhead, and deck. The diver work requirements differ considerably for these positions. For example, the diver must support the full weight of the tool in the overhead position, less of it in the vertical position, and practically none of it in the deck position.

The test stand consisted of a mild-steel structure with three adjustable legs. A 3 x 7-foot steel plate was supported in the horizontal plane and a similar plate in the vertical plane. Test plates were bolted to the vertical plate (as illustrated in Figure 8) to simulate a structure such as the side of a submerged ship. Test plates were also bolted under and above the horizontal plate to represent overhead surfaces and decklike surfaces, respectively. An adjustable staging was provided for the vertical plate to enable the divers to obtain a footing at their preferred height. Eyebolts for diver tethering were located at each side of the test plate areas.

A separate assembly was required for testing the chain saw during the harbor tests. It consisted of fir planks attached to a wooden box which held sufficient ballast to hold the assembly on the bottom. Four-inch-thick planks were attached in the vertical position and 2-inch-thick planks were attached in both the vertical and horizontal positions.

A much lighter test stand was constructed later for the ocean tests in order that it could be lowered and raised by hand from a diving boat. The basic framework was constructed from prepunched angles and panels, such as

those used to construct warehouse storage racks. Vertical, overhead, and deck working surfaces were provided with test plate and tethering attachments similar to those of the test stand in the harbor tests. Sand bags were used to level and ballast the test stand on the ocean bottom. Detailed descriptions of the various test plates used are contained in Appendix B.

A special board was constructed for use in recording performance data. The attached underwater timer was constructed by placing a conventional stopwatch in an acrylic housing. An O-ring sealed shaft passed through the housing and connected to the watch stem to permit winding and resetting. Test schedules were listed on white plastic sheets with spaces for entering performance times and notes on the working diver's performance. The plastic sheets were secured to large brass U-bolts for ease in turning the sheets. The timer and plastic sheets were attached to an acrylic base (Figure 9). Magnets attached to the far side of the base made it possible for an underwater observer to attach the timer assembly to any desired steel surface.

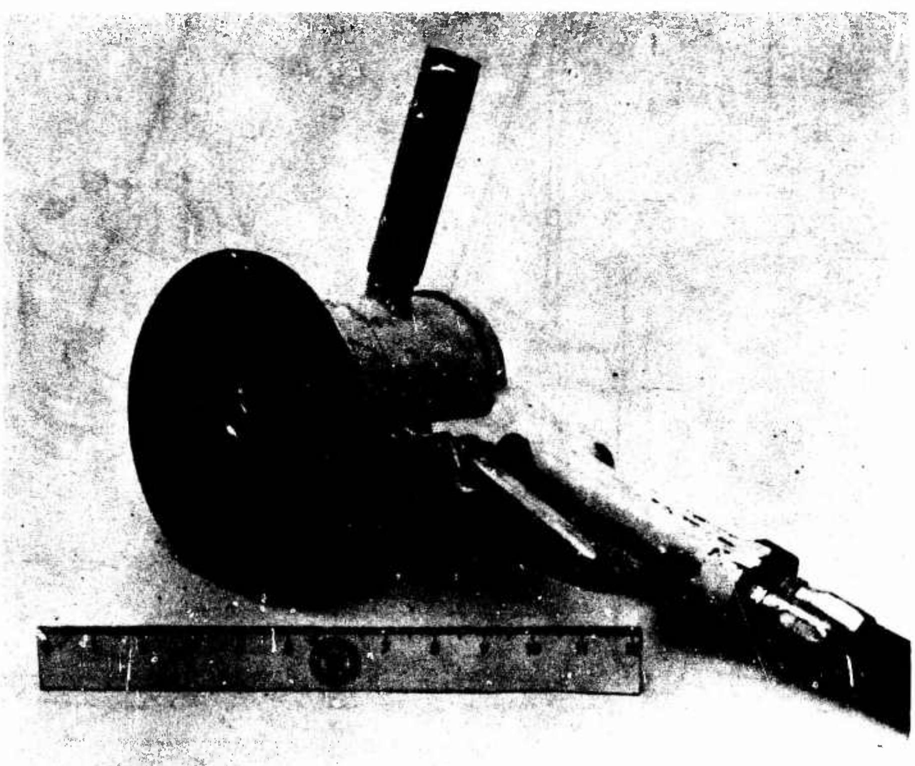

Figure 7. Hydraulic grinder.

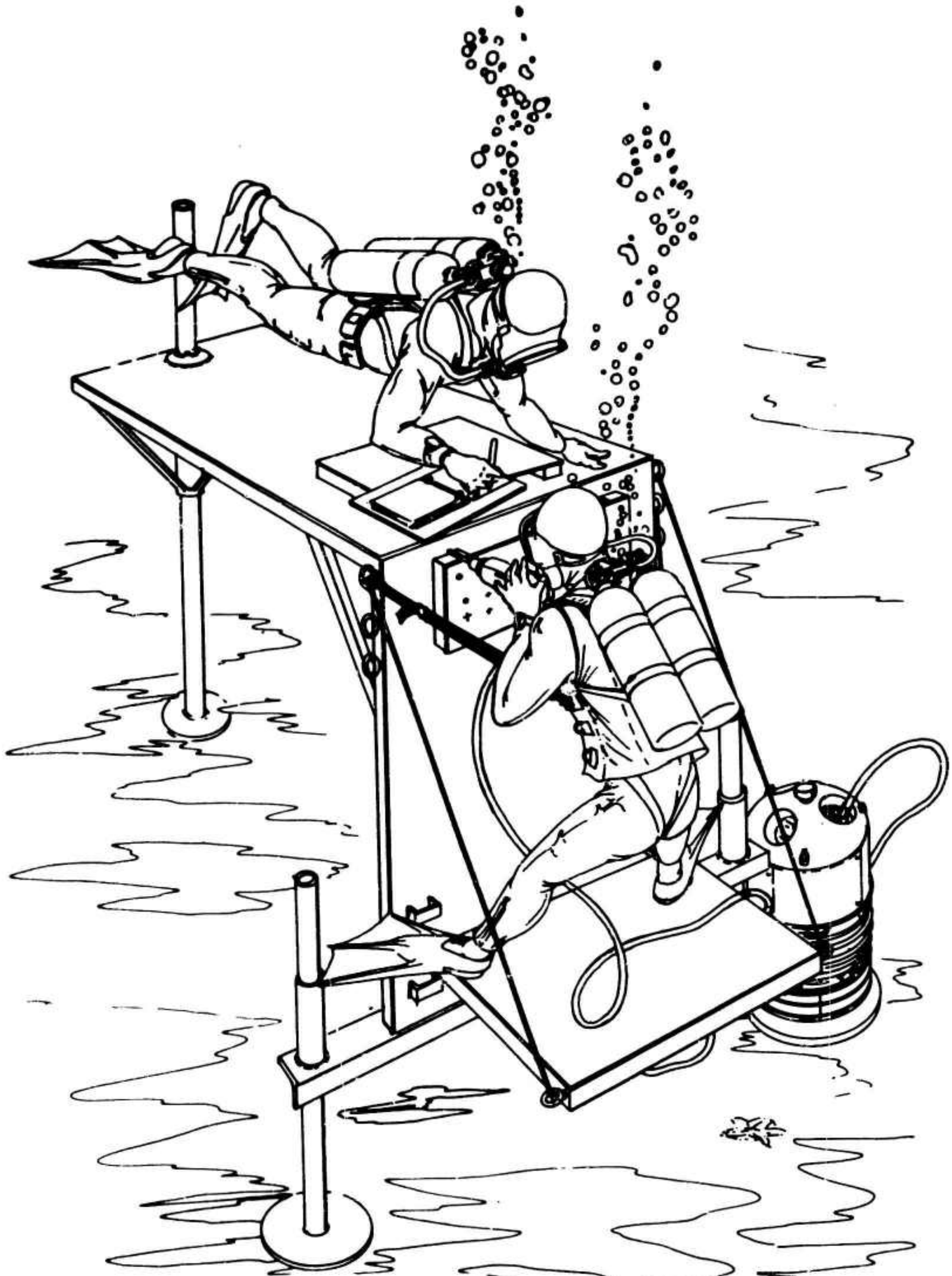

Figure 8. Harbor test stand.

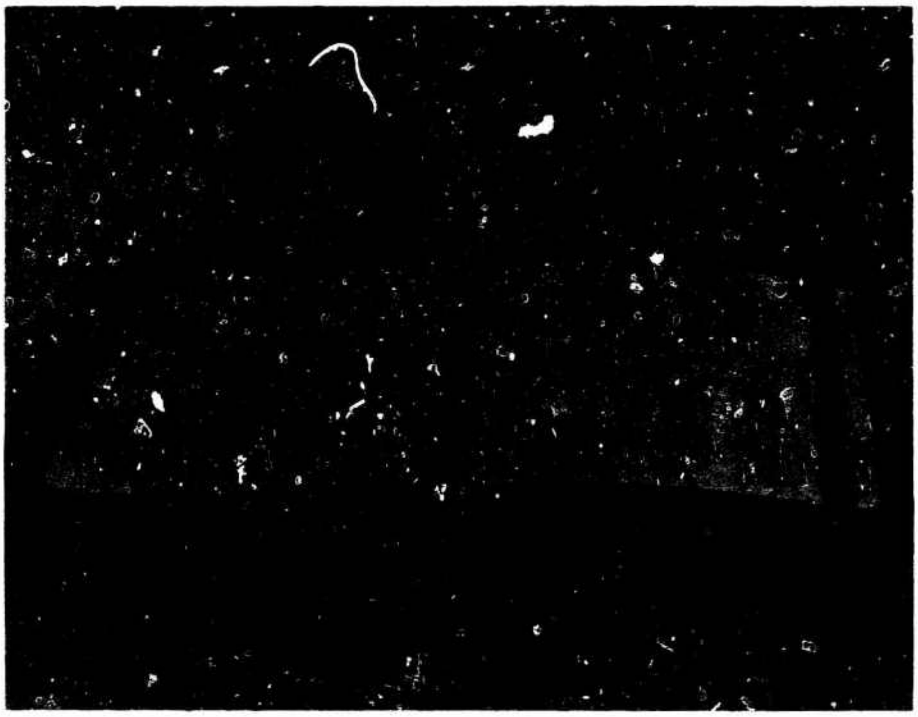

Figure 9. Underwater timer and data recording board.

The divers used conventional SCUBA equipment for all the tests conducted in the harbor. Conventional SCUBA, hard hat (deep sea), and surface-supplied band mask (Figure 10) equipment were used for the ocean tests. Wet suits were worn with the SCUBA and bank mask equipment.

The specially designed tethering harness and straps used for the tests are shown in Figure 11. Several attachment points (D-rings) were provided on the harness so that the divers could adjust the strap level to suit their individual needs. One end of the tethering strap was attached to the harness and the other end to eyebolts on the test stand. For an emergency, a quick-release buckle was built into each tethering strap so that the diver could grasp the large quick-release handles and be free to surface in a very short time. The equipment has been described fully in an earlier report.*

A metal bucket (Figure 12) was used for carrying and holding handtools, tool bits, taps, chucks, and other accessories. Nylon-lined neoprene wet suit material was attached around the inside perimeter of the bucket to form loops. The drills and taps could be arranged in order of size to facilitate selection by the diver, as the visibility was often too poor to permit reading the tool bit markings.

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* Barrett and Quirk, *op. cit.*

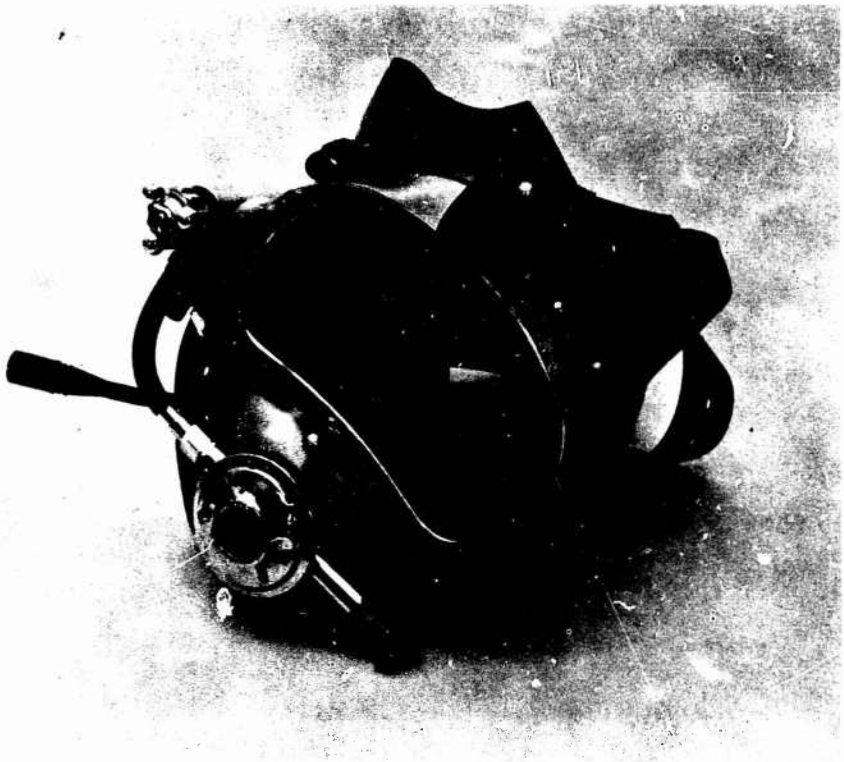


Figure 10. Surface-supplied band mask.

Figure 11. Tethering harness straps.

Figure 12. Tool holder and miscellaneous tools.

Test and Safety Procedures

Prior to each test sequence the working divers and the observation divers were briefed on the test requirements. Each working diver was provided with freshly sharpened drill bits and all other tool accessories necessary for the task.

The tasks were performed in the three basic work positions: vertical, overhead, and deck. The divers were provided with an adjustable staging while working in the vertical position. Some divers preferred to pull their knees up just below the test plates and to thrust back on the tethering harness to obtain a stable position. In the overhead position the test plate was attached to the large horizontal plate of the test stand. The divers suspended themselves from the overhead surface with the tethering straps and positioned their legs to obtain a stable position. The divers worked above the test plate in the deck position and braced themselves in a similar manner.

All harbor tests were accomplished by three Navy enlisted divers and one civilian technician diver. An attempt was made to use divers with a reasonable range of experience and training levels. Two project engineers, a Navy officer, an engineering psychologist, and two engineering technicians (all Navy-certified and experienced divers) were the underwater observers. All were familiar with the equipment and diver work methods and, as a result, were able to collect data on both tool performance and diver performance.

Carefully developed and thorough safety procedures are vital for underwater power tool operations. The tools are dangerous and capable of inflicting serious injuries, and rescue is both urgent and difficult.

Safety procedures were established for use of power tools on the surface and underwater and for rescue of an injured or otherwise incapacitated diver. The procedures were discussed with the divers and then rehearsed under operational conditions. The importance of practicing the procedures cannot be overstressed.

First-aid and resuscitation equipment and a standby diver were nearby during all underwater tool operations. A telephone was located a short distance from the harbor dive station, and emergency numbers were listed.

RESULTS

Task performance time was considered the most valid and realistic measure of tool and diver effectiveness. More complex indicators of diver workload, such as physiological measurements, were not required to obtain general guideline-type data but would be appropriate if fine distinctions were being made (as in comparing alternate modifications of the same basic tool).

Tests in Harbor

Drilling, Tapping, and Impacting Tests. This series of tests consisted of hand center punching and then drilling, tapping, and tightening bolts, using pneumatic and hydraulic impact wrenches with aluminum and steel test plates. All subtasks were performed in the three basic work positions: overhead, vertical, and deck.

Table 4 lists the subtasks and the mean times for the divers to perform the tests in the various test conditions. These data are summarized in Table 5 with respect to the three working positions. The times required to drill the various hole sizes are displayed graphically in Figure 13. The graph may be used to determine estimates of the times required to drill hole sizes other than those listed.

Table 4. Mean Times to Perform Subtasks

Subtask	Mean Performance Time (sec)			
	With Hydraulic Impact Wrench		With Pneumatic Impact Wrench	
	In Aluminum Plate	In Steel Plate	In Aluminum Plate	In Steel Plate
Drill 1/8-in. pilot hole	NA[a]	NA	13	24
Drill two 1/8-in. pilot holes	NA	NA	17	53
Drill 3/16-in. pilot hole	17	43	NA	NA
Drill two 3/16-in. pilot holes	30	129	NA	NA
Drill 1/4-in. hole in pilot hole	21	65	39	53
Drill 1/4-in. hole without pilot hole	21	117	45	83
Drill two 5/16-in. holes in pilot holes	54	180	43	121
Drill 1/8-in. hole in pilot hole	26	110	42	98
Drill 27/64-in. hole in pilot hole	30	84	57	135
Drill 1/2-in. hole in pilot hole	32	106	68	232
Tap 1/2-13 hole	24	28	70	48
Tap two 3/8-16 holes	49	49	122	110
Tighten 1/2-13 bolt	6		15	
Tighten three 1/2-13 bolts	30		37	
Center punch hole	5			
Center punch two holes	7			
Center punch three holes	15			
Center punch four holes	19			

[a] NA = not applicable.

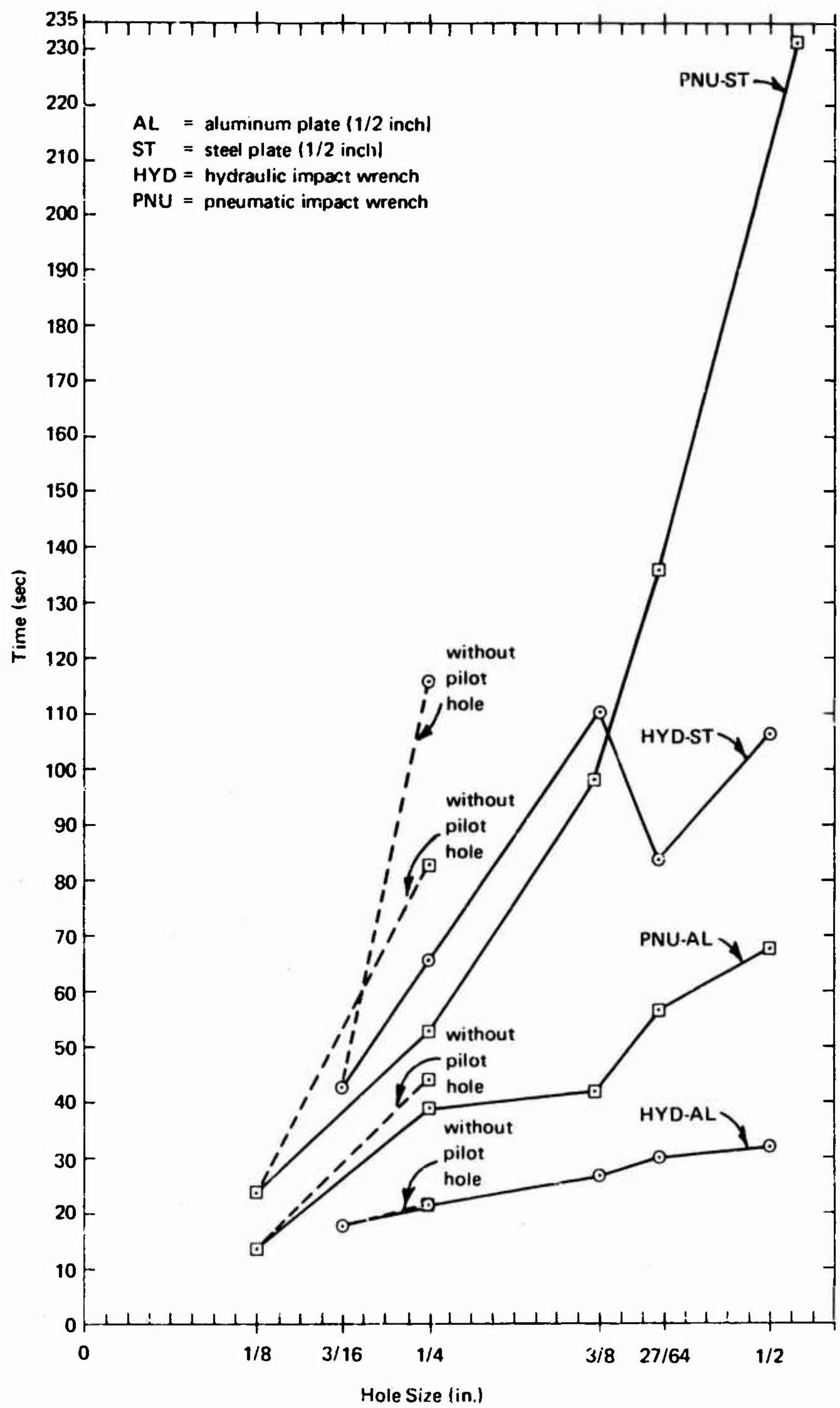


Figure 13. Mean times required to drill one hole in aluminum and steel using hydraulic and pneumatic impact wrenches.

Table 5. Mean Times for Main Task Categories as Functions of Test Plate Positions

Main Tasks	Mean Performance Time (sec) for—		
	Deck Position	Vertical Position	Overhead Position
Drilling holes	36	33	35
Tapping holes	57	67	62
Tightening bolts	22	20	24
Center punching	10	12	12

Consistently more time is required to drill steel than to drill aluminum, as might be expected. Typically, less time was required to drill aluminum material with hydraulic impact wrenches than with pneumatic. In comparison with aluminum, drilling in steel with the pneumatic impact wrench required less time for 5/16- and 3/8-inch holes but more time for 27/64- and 1/2-inch holes. The test times cannot provide a basis from which superiority of either tool type can be determined, as the hydraulic tools are of higher horsepower but develop lower tool bit rotary speed. (Informal underwater tests using realistic diver-applied forces resulted in a reduction in drill time with high drill speeds.) The data are useful in estimating diver/tool capabilities with currently available tools.

There is no significant time difference in tightening bolts, drilling, tapping, or center punching as a function of diver working position. The tethering equipment had much to do with this, as otherwise it would have been nearly impossible to support a heavy tool in the overhead position and accomplish useful work. The fact that most of the power is tool supplied rather than diver supplied also tends to result in similar task completion times.

The tightening task consisted of hand-starting 1-inch-long 1/2-13 hexagon-head bolts and then running the bolts in tight with the impact wrench. Slightly less time was required with the hydraulic wrench than with the pneumatic.

Much less time was required to tap the 3/8-16 and 1/2-13 holes with the hydraulic impact wrench than with the pneumatic. This was because the hydraulic tool developed higher torque and, thus, the tool bit jammed less frequently.

The diver scores (total mean times) for the basic test conditions are listed in Table 6 and illustrated in Figure 14. No one diver consistently performed better than the others. This is understandable, since both the tools and the test plates differ greatly; thus, one diver may function better in one condition than the other. For example, in some tasks (such as tapping) diver skill is important; for other tasks (such as drilling in steel) diver strength is more important.

Table 6. Diver Scores for Basic Test Conditions

Conditions	Sum of Subtask Mean Scores (sec) for—				
	Diver 1	Diver 2	Diver 3	Diver 4	Mean
Hydraulic tool aluminum plate	539	532	419	553	511
Hydraulic tool steel plate	1,070	1,718	740	1,332	1,215
Pneumatic tool aluminum plate	832	1,008	793	1,298	983
Pneumatic tool steel plate	1,185	2,341	1,670	960	1,539

Table 7 summarizes the data for tool and test plate types. Mean times for hydraulic tool versus pneumatic tool and for aluminum plate versus steel plate differ significantly at the 0.05 level of confidence. (The same differences could be expected to occur by chance alone approximately five times out of a hundred if there were, in fact, no real difference.) This could be expected since, first, the hydraulic tool delivers more power than does the pneumatic tool and, second, that aluminum is softer than mild steel.

The relative amounts of time spent in productive versus nonproductive time are listed in Table 8. The keyless drill chucks on the pneumatic impact wrench repeatedly jammed, resulting in much lost time and a greatly reduced percentage of diver productive time. The key chucks on the hydraulic impact wrenches were less difficult to use.

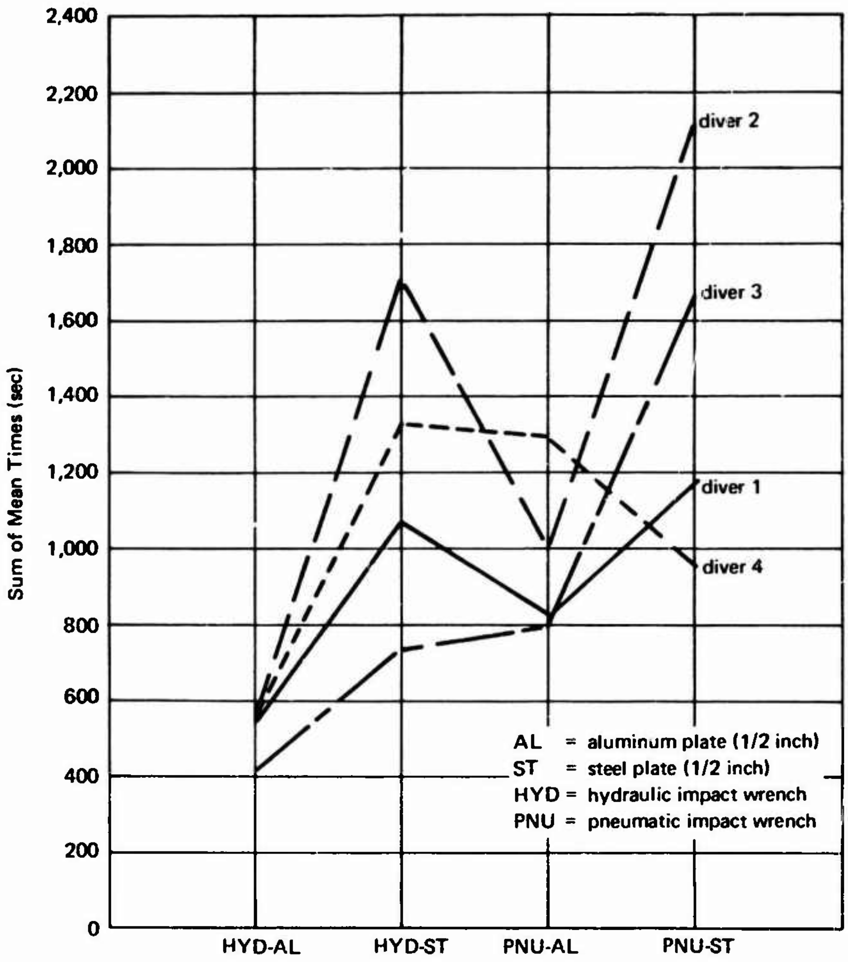


Figure 14. Mean times for test divers.

Bolt and Nut Torque Tests. The hydraulic impact wrench and impact test plate previously described were used. All bolts and nuts were pretightened on the surface prior to commencing any one series of tests. The bolts and nuts were loosened and then retightened with the impact wrench. All tests were performed in the overhead, vertical, and deck work positions. Both mild-steel and stainless-steel bolts were used.

Table 7. Mean Times for Basic Tool and Test Plate Types

Category	Mean Performance Time[a] (sec)
Hydraulic impact wrench	863
Pneumatic impact wrench	1,261
Aluminum test plates	747
Steel test plates	11,377

[a] Summarized from Table 4 data.

Table 8. Productivity Percentages for Divers

Diver	Percent Productive[a] With—	
	Hydraulic Tool	Pneumatic Tool
1	40	46
2	31	52
3	46	44
4	42	32
Mean	40	44

[a] Productive time is time actually spent drilling, tapping, etc., in contrast to time spent changing bits, securing tools, etc. Percent productive = (productive time/total time) x 100.

The mean times required to perform the various tasks under different work positions, bolt material and size, and bolt orientation conditions are listed in Table 9. Slightly less time was required to remove and replace the smaller bolts and nuts than the 1-1/4-inch size, but there was no consistent difference as a function of bolt material. Slightly more time was required to perform the tasks in the overhead position than in the vertical or deck positions, but the 2 second time difference is not significant. There was no significant difference between removing or replacing a bolt with the nut tack welded or one with the bolt free to rotate.

Table 9. Mean Times for Bolt and Nut Removal and Replacement With Hydraulic Impact Wrench

Category	Performance Time (sec)							
	1-1/4-in. MS[a]	1-in. MS	1-in. SS[b]	3/4-in. MS	3/4-in. SS	1/2-in. MS	1/2-in. SS	Mean
Mean removal time; combined work positions	14	14	9	7	6	6	6	9
Mean replacement times; combined work positions	11	7	6	6	6	6	6	7
Mean removal and replacement times								
Overhead	13	11	10	8	7	7	6	9
Vertical	11	10	7	5	5	6	6	7
Deck	12	10	5	6	6	5	7	7

[a] MS = mild steel.

[b] SS = stainless steel.

Chain Sawing Tests. The chain saw and test assembly previously described were used. The tasks consisted of crosscutting and ripping 18-inch-long cuts in both 2- and 4-inch-thick planks with the planks running horizontally and vertically. Task performance times are listed in Table 10. Consistently less time was required to cut the 2-inch than the 4-inch material except for diver 4. His performance was generally less stable than that of the other divers, and the times are probably more indicative of his performance variability than real differences in tool performance. There was no significant difference between crosscutting and ripping times.

Grinding Tests. The hydraulic grinder and test plate previously described were used. The tasks consisted of:

1. Grinding a 7-inch-long burn-cut edge of a 1/4-inch-thick steel plate to a 45-degree angle (such as would be used in butt welding).
2. Grinding a weld bead flat for 2 inches of its length.
3. Grinding off a 1/2-13 hexagonal bolt head.
4. Grinding off a 1/2-13 hexagonal nut.

The data are listed in Table 11. All tasks were performed in the vertical and overhead positions; there was no significant difference because of position. The divers' performance times varied considerably, with those of diver 4 again being less stable.

Table 10. Hydraulic Chain Saw Data

Condition	Performance Time (min) for—				
	Diver 1	Diver 2	Diver 3	Diver 4	Mean
Crosscut[a]					
2-inch plank	0.9	1.7	0.6	4.8	2.0
4-inch plank	1.6	3.1	1.4	1.3	1.9
Rip[b]					
2-inch plank	0.8	1.8	0.9	3.8	1.8
4-inch plank	1.9	2.2	1.8	3.2	2.3

[a] Crosscuts—against the wood grain.

[b] Rip cuts—parallel to the direction of the grain.

Tests in Ocean

A limited number of tests were conducted in the ocean. These tests used the hydraulic impact wrench, saw, grinder, and the grinder test plate previously described. A 2 x 12-inch fir plank was attached to the test stand for the chain saw tests. The test objectives were:

1. To observe the function of the hydraulic tools in the ocean at a moderate depth.
2. To test a diesel hydraulic power supply unit.
3. To compare diver performance using three different types of diver equipment.
4. To test the practicability of the lightweight portable test stand.

Table 11. Hydraulic Grinder Data

Task	Diver	Performance Time (min)		
		Work Position		Mean
		Vertical	Overhead	
Grind weld flat for 2 inches	1	5.5	3.3	–
	2	3.3	3.3	–
	3	4.5	3.2	–
	4	5.3	12.6	–
	mean	4.7	5.6	5.2
Grind edge to 45 degrees for 7 inches	1	1.7	1.3	–
	2	2.5	1.1	–
	3	3.3	0.8	–
	4	3.8	3.4	–
	mean	2.8	1.7	2.3
Grind off bolt head	1	3.8	1.8	–
	2	2.8	1.4	–
	3	5.3	5.2	–
	4	8.9	16.7	–
	mean	5.2	6.3	5.8
Grind off nut	1	6.9	5.0	–
	2	4.2	5.4	–
	3	4.7	5.2	–
	4	4.7	6.2	–
	mean	5.1	5.5	5.3
Grand Mean		4.5	4.8	–

The test data are listed in Table 12. A direct comparison of diver performance times is meaningless, as the performance was affected by both individual work capabilities and diving gear type. Observations of a more general nature are:

1. The hard hat diver stated it was much more difficult to move around on the test stand and to work with the tool because arm movement was restricted in the inflated suit.

2. There was a greater necessity for care on the part of the surface-supplied divers (band mask and hard hat), because it was possible to damage their air hoses with the power tools, especially the chain saw.

3. The diver using the band mask stated he had excellent maneuverability, visibility, and comfort.

4. Conventional SCUBA gear is excellent for this type of work except for the more limited air supply.

5. The chain saw performed very well, and the hydraulic impact wrench was excellent for drilling but lacked sufficient torque to remove the 1-1/4-inch bolts. Extensive use had been made of the tool, and it had lost some of its original power.

Table 12. Data From Tests in Ocean

Task	Performance Time (min:sec) for—		
	Diver 1[a]	Diver 2[b]	Diver 3[c]
Saw 2 inches off plank	0:09	0:09	2:00
Grind weld bead flat for 2 inches	4:00	–	2:35
Grind one edge to 45 degrees for 7 inches	2:20	–	1:50
Center punch three places	0:03	–	0:10
Drill two 3/16-inch pilot holes	0:45	–	1:30
Drill one 3/8-inch hole in pilot hole	0:04	–	0:17
Drill one 1/2-inch hole in pilot hole	0:20	–	0:32
Loosen six 1-1/4-inch bolts	*d*	*d*	*d*

[a] Hard hat diving gear.

[b] SCUBA diving gear.

[c] A shallow-water band mask and wet suit.

[d] Impact wrench would not loosen bolts.

DISCUSSION OF RESULTS

Power Tools

Both the pneumatic and hydraulic tools proved reliable; however, the pneumatic tools are much more time-consuming to maintain, as explained in the maintenance section of Appendix C.

Two types of pneumatic tools were used. Both tools were standard 1/2-inch impact wrenches requiring 7 cfm of gas at 90 psig. These tools have rotary vane motors with a free speed of 7,000 rpm. In the first tool (shown at the top of Figure 15), the vanes were held against the cylinder wall by air channeled from the air supply. Because seawater entered the exhaust port when the tool was not in operation, these air ports became clogged with foreign matter and the motor stalled frequently. Stalling was experienced both under no-load and excessive load conditions. Maintenance of this tool was difficult because the motor section was pressed into the tool housing, resulting in excessive disassembly time. The second tool utilized spring-loaded vanes which eliminated motor stalling unless the load exceeded the power rating. Maintenance was relatively simple because the motor section was not pressed into the housing.

The hydraulic grinder was a difficult tool to use underwater, as the action of the grinding wheel on the work tended to pull the grinder along. Furthermore, considerable thrust had to be applied for the grinding wheel to cut rapidly, as the water had slight lubricating properties. Essentially, this meant the diver had to use both hands to hold the tool and, therefore, required tethering or staging and extra weight to hold his position. Some of the test divers stated the tool lacked sufficient power, as it was possible to stall it out. The stalling, however, was attributable to the fact that only approximately 5 hp was available from the remote power supply. The tool is rated at 6 hp, and, with full power available, stalling might not have occurred.

All of the hydraulic tools tested were much more effective with optimum work techniques, including establishing good body position to gain stability, applying the correct thrust, and understanding the functional characteristics of the tool. For example, too little force while drilling results in a very slow cutting rate, while too much force causes tool bit jamming.

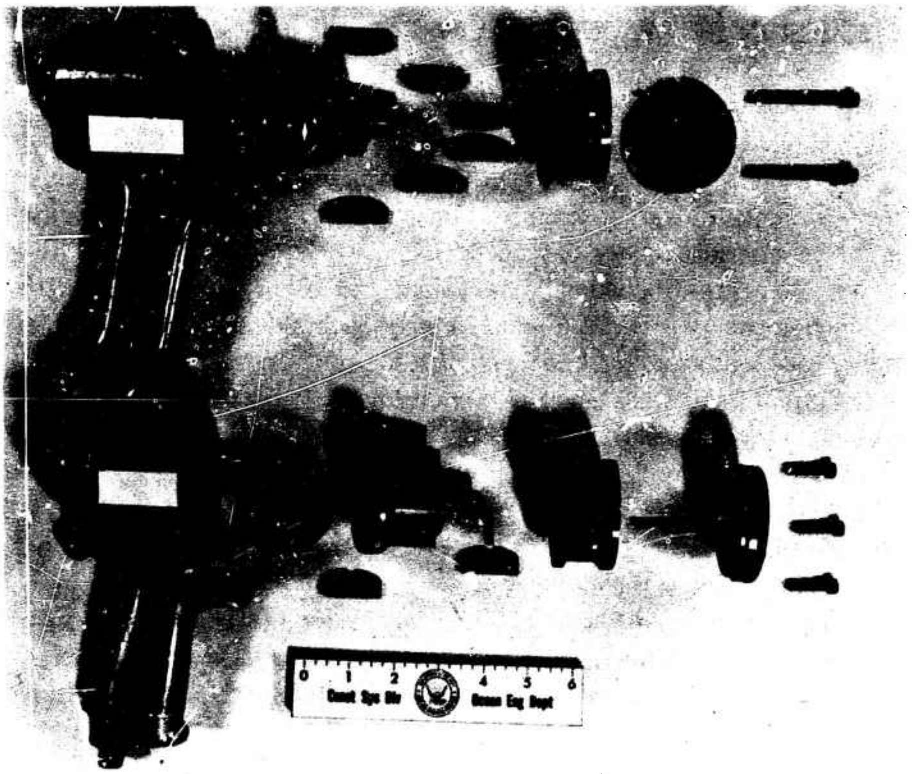


Figure 15. Pneumatic tools disassembled to show contrasting vane types.

Hoses and Connectors

Hydraulic fluid supply and return hoses are generally stiff and do not swivel properly. The diver must typically exert some extra force just to get the tool into proper position and to hold it there against the resistance of the hoses. If there is surge or current, the problem is compounded. At times it is necessary to secure the hoses to the work site structure to relieve the diver of the excessive pull. The hoses were very heavy for the tenders on the support craft to pull up, although the 60-foot work depth was relatively shallow.

The connectors on the hydraulic hoses would accidently disengage as they were pulled over the work boat gunwale if extra care was not taken. Hose for the pneumatic tools was less of a handling problem, because the hose was smaller in diameter and more flexible. A long hose would, nevertheless, be adversely affected by surge and current.

Drill Chucks

As explained in Appendix A, the drill chucks presented such a great problem that extensive rework was necessary in order to conduct the tests. The modified chucks, although a distinct improvement, were not entirely satisfactory. A disproportionate amount of time and effort was required to change tool bits when frequent changes were required.

Holding and Carrying Equipment for Tool Accessories

No real effort was made to develop the most effective equipment for accessory handling and carrying, as this was outside the scope of the tests. The metal bucket used was similar to the conventional diver's tool bag except that tool bit loops were provided around the inside. It was simple and fast to select the desired tool bits when they had been arranged in order. The principal problem was the difficulty of seeing and selecting the correct impact wrench socket, punch, or other accessory from the general contents without dumping everything out of the bucket. The generally poor visibility in the harbor compounded the problem. The overall weight of the accessories used was not excessive but could well become so if the accessories were to be handled by a free-swimming diver.

Diver Training

Many commercial diving companies recommend selecting highly skilled craftsmen as a first consideration and training them to be divers if necessary. Diver/tool tests conducted at this station tend to corroborate this policy. When prior skill and knowledge of the tools and work techniques have not been achieved, it is recommended the divers be given special instruction in effective use of the tools and related underwater work methods.

CONCLUSIONS AND RECOMMENDATIONS

1. The hydraulic tools were very effective and practical at test depths and should be equally effective at much greater depths. Pneumatic tools lose efficiency as the depth increases and are not recommended for deep-diving operations (beyond 120 feet). Detailed conclusions and recommendations for the various tools and accessories are listed in Table 13.

Table 13. Conclusions and Recommendations for Tools and Accessories

Item	Conclusions	Recommendations
Pneumatic impact wrench	Depth limited and requires excessive maintenance, but light and relatively easy to handle.	Design for ease in assembly and disassembly to facilitate maintenance.
Hydraulic impact wrench	Very effective for drilling, tapping, and bolt and nut impacting; controls should be improved.	Move Forward–Reverse control to the rear of the motor where it is more accessible. Conduct tests to determine if On–Off control can be released rapidly in an emergency; if not, modify. Conduct tests to determine optimum rotary speed for drilling, using realistic driver applied forces.
Hydraulic chain saw	Effective for light use, but lacks adequate power for heavy work; some modifications are required.	Modify handle and add adjustable dog (Figure 16). This will permit the operator to exert force directly in line with the saw chain and to gain more leverage in cutting.
Hydraulic grinder	Very effective for underwater use, but difficult to handle; both hands are required for operation; tethering and/or staging required.	Modify On–Off control as described in Appendix A. Conduct tests to determine optimum grinding wheel materials, peripheral speeds, and configurations.
Hoses and connectors	Pneumatic hoses adequate, but hydraulic hoses stiff and lack proper swivel mechanisms at the motor connection.	Tests should be conducted to determine if lighter, more flexible hoses can be used. The feasibility of using concentric hoses with the supply hose located inside the return hose and a single swivel connector should be investigated. The swivel should be designed to permit rotation in two planes as illustrated in Figure 17.
Tool accessories	Both the keyless and key-type chucks were time-consuming to use and jammed when using the impact mode. Tool-holding devices were not entirely satisfactory as it was difficult to locate the tool accessories, especially in murky water.	All tool bits should be provided with adapters that would permit direct mating to impact motor for maximum diver efficiency. Special tool-holding devices should be fabricated to permit prearrangement of all tool bits by size. All items should be visible and accessible to the diver.

2. Diver skill in effective tool utilization is very important, and a knowledge of safe handling procedures is mandatory. Selection and training of divers in the use of tools underwater is necessary for optimum safety and work effectiveness.

3. All of the power tools, and in particular the chain saw, are potentially dangerous. Thorough procedures must be established for safe tool use, general diving safety, and rescue techniques.

4. The use of SCUBA gear provides the working diver with greater freedom for positioning on the work surfaces. With surface-supported diving systems the diver must take added precautions to ensure that his life line and air hose do not become entangled with the tool umbilicals or damaged by the tool.

ACKNOWLEDGMENT

The following personnel, in addition to the authors, served as underwater observers:

R. Elliott, LTJG, USN
D. Phillips, Electronics Technician
J. Quirk, General Engineer
M. Sheehan, Engineering Technician

The test divers were:

A. Berg, BU2/DV
A. Calvert, UT2/DV
D. Lind, DU3/DV
D. Phillips, Electronics Technician
A. Ryles, BM2/DV
M. Sheehan, Engineering Technician
V. Tripp, EN3/DV

All observers and test divers were Navy-certified divers. A special effort was made by all participants to note the actual problems encountered and to make recommendations for corrective action where possible.

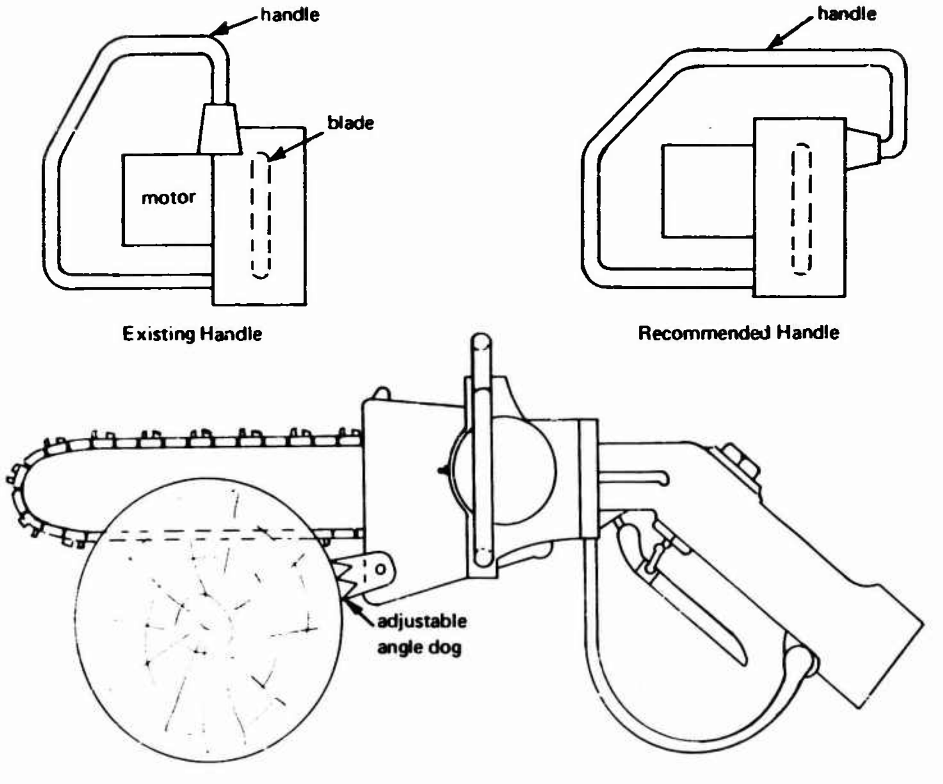


Figure 16. Proposed chain saw modifications.

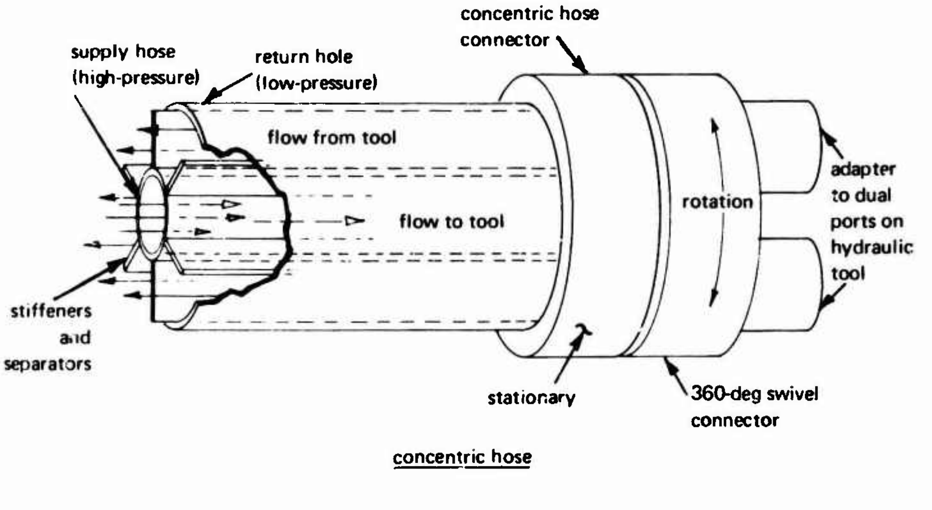


Figure 17. Proposed hydraulic hose and connector modifications.

Appendix A

POWER TOOL AND ACCESSORY MODIFICATIONS

Initial testing of the hydraulic tools prior to the evaluations indicated that some modifications were necessary to provide for easier diver operation. The modifications involved such items as lengthening operating handles and handle guards to fit the diver's entire hand.

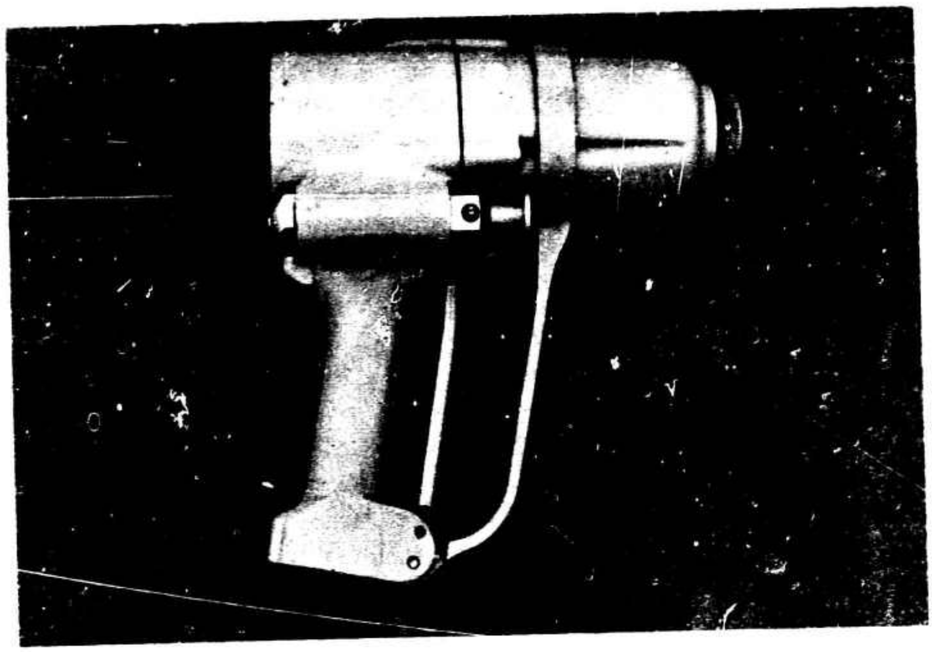
Figure A-1 shows the hydraulic impact wrench prior to and following modifications. Initial testing showed that the diver's hand became fatigued after short-term operation of the tool. This was primarily because excessive force was required to hold the operating lever depressed. The manufactured version was so configured that the diver lost mechanical advantage when depressing the lever; thus, more force was required than necessary. The pivot point of the handle was therefore moved to the opposite end of the operating lever, reducing the force required.

Figure A-2 shows the manufactured version of the hydraulic chain saw and the tool after modification. The operating lever was originally designed to be triggered with one finger. In the modified version, the lever was changed so that the entire hand could be used. This necessitated increasing the size of the operating lever guard so that easy access could be gained. During the course of the tests, the saw was further modified by adding the spikes or dogs shown on the modified tool. This enabled the divers to dig the spikes into the planks being cut and gain better cutting leverage. A sighting mark was added to aid in obtaining straighter cuts.

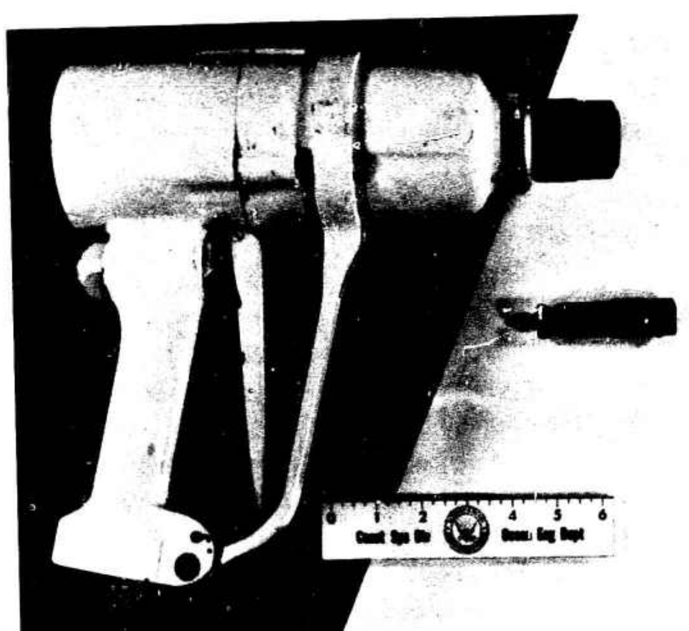
A common problem with most pneumatic tools tested has been that the air exhaust from the tools partially obscures the diver's view, thereby increasing the difficulty of use.

The hydraulic impact wrench functioned very reliably and effectively. The impact mechanism caused very little countertorque to be applied to the diver. Consequently, the approximately 3-1/2 hp developed was not excessive, but it would have been difficult and dangerous to control the wrench during drilling operations without this feature. The Forward–Reverse lever was in an awkward position, and the direction of movement of the lever in relationship to motor rotation was reversed. The impact wrench would not remove the large 1-1/4-inch bolts during the ocean tests, but it had proved adequate during the earlier harbor tests before the impacting mechanism became worn.

One of the test divers stated that the On–Off handle was too long on all of the hydraulic tools and would be difficult to release rapidly in an emergency (Appendix D).

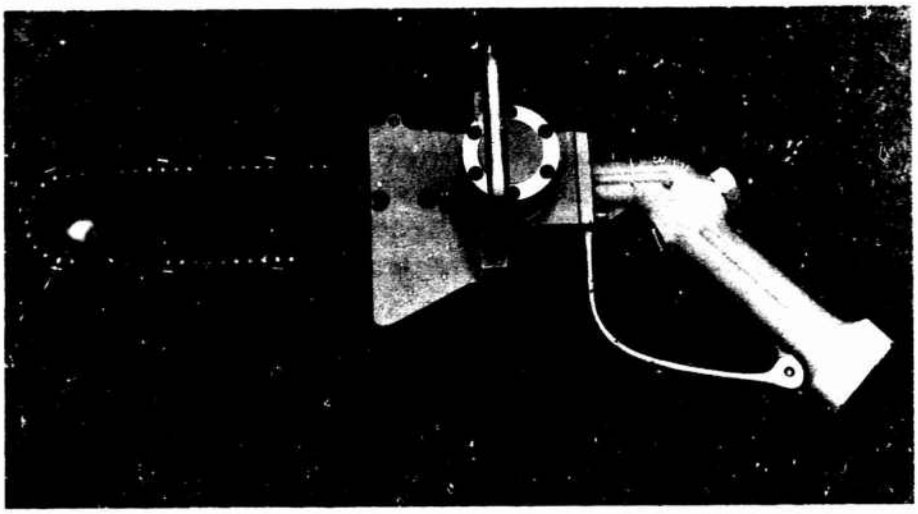


(a) Unmodified tool.

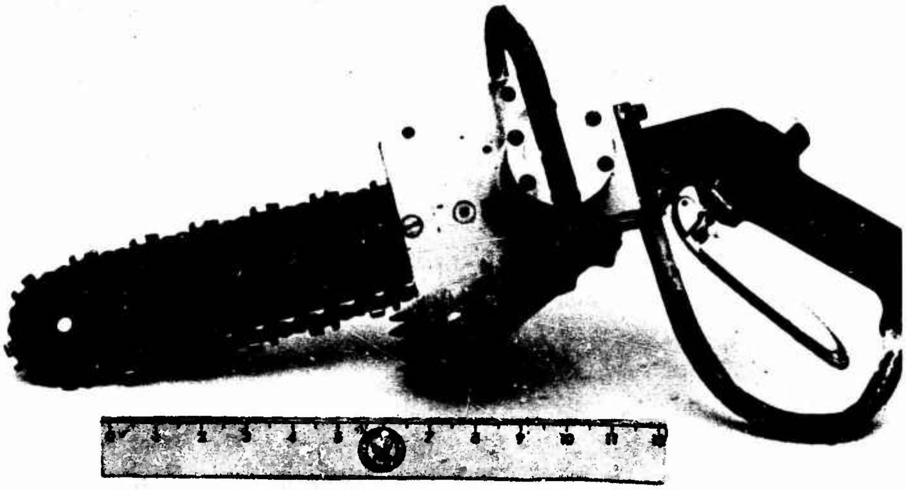


(b) Modified tool.

Figure A-1. Hydraulic impact wrench.



(a) Unmodified saw.



(b) Modified saw.

Figure A-2. Hydraulic chain saw.

The hydraulic chain saw was designed for light work, such as tree trimming. It performed very well for cutting 2-inch planks but probably would be inadequate for cutting large-diameter piling. Addition of the dogs (Figure A-2) improved the efficiency of the saw, as the operator could then rotate the chain into the work. He otherwise would have to "push" the saw into the work, a more difficult task because of relative weightlessness and typical lack of good footing. This tool is potentially dangerous underwater and must be handled with great care. It is somewhat difficult to cut on a straight line, as the visibility is often poor. Also, it is often difficult to get in a position where the actual cut can be observed, because the housing tends to obscure the view. A mark on the housing, in line with the chain, was of some help in this regard.

The guard was removed from the hydraulic grinder for the underwater tests. This aided divers in positioning the grinding disk and observing the cut. The water medium and the fact that the divers wore masks reduced the hazards of operating without a guard. The trigger and guard were modified in the same fashion as the chain saw (Figure A-3).

The hydraulic impact wrench was equipped with a quick-change chuck that facilitated the connection of different tool adapters. This was a standard 3/4-inch key chuck with a 5/8-inch hexagonal quick-change adapter. A grease nipple was added to the chuck to accommodate post-dive maintenance. The chuck key was modified to provide the diver with additional mechanical advantage. Figure A-4 shows the modified drill chuck and chuck key.

As stated in the **Results** section, considerable problems were encountered with the drill chucks. This was particularly true with the chucks on the pneumatic impact wrench. Excessive time was required to change tool bits because of jamming of the chuck mechanism. Two attempts were made to solve this problem. The first method was to grind flats on the outer sleeve of the chuck (Figure A-5), so that a pipe wrench could be attached to the chuck for better gripping action. This proved to be too awkward for divers to handle. In the second method, the outer surface of the sleeve was knurled to provide better gripping action and was equipped with four equally spaced holes so that a breaker bar could be used when hand removal was not possible. This system was easier to operate than either the standard chuck or the chuck with the flats, but on occasion the chuck mechanism jammed and could not be loosened underwater.

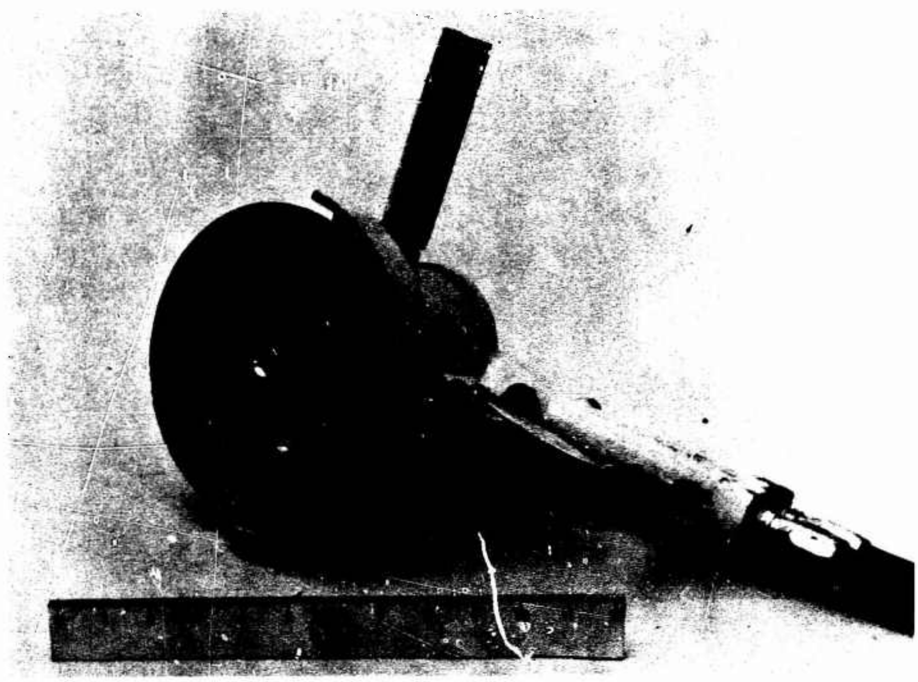


Figure A-3. Modified hydraulic grinder.

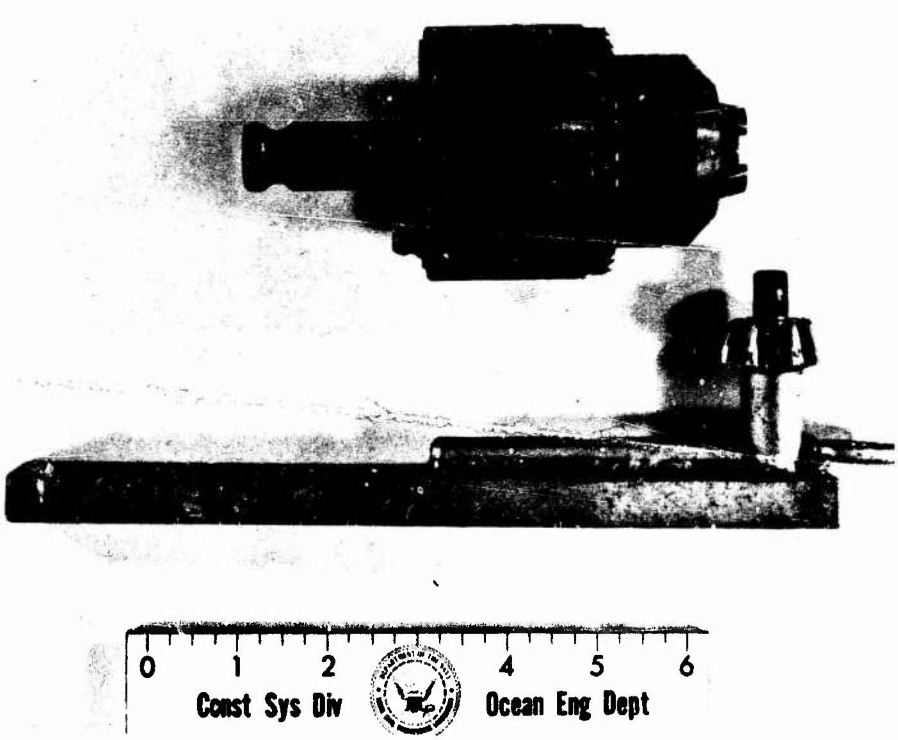


Figure A-4. Key-type chuck.

Figure A-5. Keyless chucks.

Appendix B

TEST PLATES

The test plate used for drilling, tapping, and impacting tests was a sheet of 1/2-inch-thick boiler plate approximately 12 inches by 22 inches. Clearance holes for attaching the plate to the test stand studs with wing nuts were provided.

A test plate for the bolt and nut torque tests was fabricated using a 1/4 x 17 x 20-1/2-inch steel sheet (Figure B-1). The plate had clearance holes for the following bolts (all with lock washers and hexagonal-head nuts):

No. of Bolts	Designation	Length (in.)	Material
12	1-1/4-7	2	mild steel
6	1-8	2	mild steel
6	1-8	2	stainless steel
6	3/4-10	2	mild steel
6	3/4-10	2	stainless steel
6	1/2-13	1-1/2	mild steel
6	1/2-13	1-1/2	stainless steel

Three basic bolt—nut configurations were used: (1) bolt heads welded to the back of the plate, (2) nuts welded to the back of the plate, and (3) unwelded with bolt heads at the back of the plate.

Lock washers were placed under the nuts except where the nuts were welded, in which case they were placed beneath the bolt heads. The bolts and nuts were pretightened to the following foot-pound limits:

Bolt Designation	Pretightened Limits (ft-lb)	
	Mild Steel	Stainless Steel
1-1/4-7	432	546
1-8	236	299
3/4-10	105	132
1/2-13	39	45

Clearance holes in the test plates were provided for attachment of the assembly to the test stand studs with wing nuts.

A test plate (Figure B-2) was designed for the hydraulic grinder to provide three basic test conditions: (1) burn-cut plate edges to be ground to 45-degree bevels such as would be required prior to welding, (2) approximately 1/2-inch-wide weld beads to be ground flat, and (3) bolt heads to be removed by grinding. The test plate was cut into an octagonal shape from a 1/4-inch-thick by 36-inch-diameter sheet of mild steel. The plate was stiffened by welding a 1-1/4 x 1-1/4-inch angle iron framework to the rear of the plate. The octagonal shape provided eight flat surfaces approximately 14 inches long for bevel grinding. Eight weld beads, 24 inches long, were evenly spaced on the plate face, as were the clearance holes for the eight 1/2-13 bolts. Two clearance holes were drilled to allow for attachment to the test stand and one larger hole for lift line attachment.

Figure B-1. Test plate for hydraulic impact wrench tests.

Figure B-2. Test plate for hydraulic grinder tests.

Appendix C

TOOL MAINTENANCE

GENERAL

As mentioned in the main text of this report, pneumatic tools require more maintenance than do hydraulic tools. This is primarily because salt water enters the motor sections of the pneumatic tools while they are not in use. Hence, bearings and other moving parts are subject to contamination and corrosion.

PNEUMATIC IMPACT WRENCH

The pneumatic impact wrench used during the tests was completely disassembled after each dive to accomplish the following:

1. Removal of foreign materials from motor section and air channels.
2. Removal of salt water from bare metal parts.
3. Lubrication of bearings and frictional surfaces.
4. Application of protective coating on exposed metal parts.

It should be pointed out that repeated disassembly of high-speed motors such as the vane motor of the pneumatic tool is undesirable, since close-tolerances are required.

HYDRAULIC IMPACT WRENCH

The impact section of the hydraulic tool was disassembled after each day's operation. This was necessary because the O-ring seal on the shaft was not adequately sealed, enabling seawater to enter the impactor housing. Lubricative and protective coatings were applied where appropriate.

On two occasions damage to the internal gear of the impact mechanism resulted in stalling of the tool. Both occasions were the result of using the tool beyond the manufacturer's recommended torque ratings. Metal particles breaking off the hammer and anvil became lodged between two teeth of the internal gear. This resulted in a tooth being broken from the spur gear.

HYDRAULIC CHAIN SAW

No major problems were encountered with the chain saw. After each day's operation all exposed metal parts and bearings were cleaned, lubricated, and coated with protective lubricants. The saw chain was sharpened after each day's use. The saw chain repeatedly loosened underwater, requiring periodic retightening.

HYDRAULIC GRINDER

The hydraulic grinder was the easiest tool to maintain, because there were no external exposed gear sections. After each day's use the tool was sprayed with a protective lubricant.

Appendix D

DIVER QUESTIONNAIRE AND DEBRIEFING DATA

The participating divers were instructed to take particular notice of the problems they actually experienced while working with the tools and accessories underwater and to suggest ways the problems could be overcome or reduced.

The following divers (listed alphabetically) participated in the hydraulic impact wrench, chain saw, and grinder tests and filled out questionnaire forms after each series of trials. The experience level and diving training of each is listed.

A. C. Calvert, UT2/DV—Underwater Swimmers' School, Second Class Divers' School, with 2 years of diving experience.

A. A. Ryles, BM2/DV—Second Class Divers' School, with 9 years of diving experience.

M. E. Sheehan, Civilian—Second Class Divers' School, with 2 years diving experience.

V. D. Tripp, EN3/DV—Second Class Divers' School, with 6 years of diving experience.

The questionnaire data are arranged separately for each of the three major hydraulic tools: impact wrench, chain saw, and grinder. The replies appear in random order.

HYDRAULIC IMPACT WRENCH

1. How much do you think your ability to handle the tool was improved by the tests we completed?

A. None.

B. Moderately.

C. Greatly.

D. None.

2. Do you believe that salvage and construction divers should be trained to use this tool?

A. No. Any diver could use the tool.

B. No.

C. Briefly.

D. No. Any Navy diver should be able to use the tool with satisfactory results.

3. Was the trigger comfortable?

A. The trigger was too close to the front of the guard. With gloves on, I couldn't release it fast enough.

B. Yes.

C. Yes.

D. No. It was too long with too much travel. You didn't have good enough control of pressure to the wrench.

4. Was the Forward–Reverse lever difficult to use?

A. No.

B. No.

C. Yes. You need something more positive to get a grip on.

D. With gloves, yes; without them, no.

5. Was the handle comfortable?

A. Yes.

B. Yes.

C. Yes.

D. Yes.

6. Could you operate the tool effectively with one hand?

A. No. A larger person probably could.

B. Yes.

C. At times. It depends on the orientation of the diver to the work. The diver could even hold the tool in the over head position without becoming overly tired.

D. Yes.

7. Was the torque imparted to you excessive?

A. Yes.

B. No.

C. No.

D. No. Less than I expected. It was hardly noticeable.

8. Was it difficult to change sockets?

A. No.

B. No.

C. At times. The sockets could be all of the same type. This would save time when it came to removing the sockets from the tool

D. New sockets—yes; worn sockets—no. This aspect could be improved.

9. Did the sockets come loose accidently?

A. No.

B. No.

C. Rarely. Most of the sockets would lock in positively with a ball and socket.

D. Very rarely.

10. Could you avoid overtightening the smaller bolts?

A. No.

B. Yes, with a little practice.

C. Yes.

D. Yes, with a working knowledge of the tool.

11. Did you have any problem with bolts or nuts vibrating loose and falling off?

A. Yes.

B. No.

C. Yes.

D. Overhead, yes; otherwise, no.

12. Did the hydraulic hoses make it difficult to position the tool?

A. Yes.

B. No.

C. Yes.

D. In awkward positions—like working overhead—it did.

13. Do you believe the tethering harness was necessary?

Vertical

A. Yes

B. Yes.

C. No.

D. No.

Deck

A. No.

B. Yes.

C. No.

D. No.

Overhead

A. Yes.

B. Yes.

C. Yes.

D. No.

14. Did you use any special technique to improve the effectiveness of the tool?

A. No.

B. No.

C. The ability to know what is happening through sound rather than sight helps a lot.

D. Yes. Short bursts of power at times worked best.

15. Was there any confusion of the position of the Forward–Reverse lever and the direction of rotation?

A. No.

B. No, but it was necessary to understand the tool.

C. No.

D. As it was not marked, I had to watch the socket when I first started to see the direction of rotation. No problem.

16. Was the weight of the tool excessive?

A. After using it awhile my shoulders would get a little tired.

B. No.

C. No, but it could be reduced.

D. It wasn't noticeable except in the vertical position.

17. Did the tool develop enough torque to remove all the large bolts and nuts?

A. Yes.

B. Yes.

C. Yes, but with some difficulty.

D. Yes.

HYDRAULIC CHAIN SAW

1. Was the tool safe to use underwater?

A. Yes.

B. Yes.

C. With extreme caution, yes.

D. No. Too much of the blade is exposed. The trigger should be shorter and easier to release.

2. Was it necessary to wear extra weight to use the tool effectively?

A. Yes.

B. Yes. Ten pounds extra.

C. Yes. A diver would have to be 30 or 40 pounds negative to use the tool effectively without tethering.

D. No.

3. Did the tool cut rapidly enough both crosscutting and ripping to be effective for underwater construction?	A. Yes. B. Yes. C. Yes. D. Yes. The blade could be longer, but it cut fast enough.
4. Do you believe the tool should be more powerful? If so, how much more?	A. No. B. No. C. Yes. Its capacity isn't nearly enough for heavy jobs like cutting 12- or 14-inch-diameter piling. D. No. It is adequate now.
5. Are both hands required to use the tool?	A. Yes. B. Yes. C. Yes. D. No. The saw can be used with one hand after the cut is started.
6. Is tethering desirable in using the tool?	A. Yes B. Yes. C. Under certain circumstances, yes. D. This depends upon the job. It helps if the diver is cutting small wood in one place.
7. Do you believe operators should receive special training in use of the tool?	A. No. B. No. C. Yes. D. Yes. They should be shown how to use the dogs on the bottom of the tool to grip the wood.
8. Was the training you received adequate?	A. Yes. B. Yes. C. Yes. D. Yes.
9. Do you have any design change recommendations?	A. No. B. Yes. A blade marker should be added to the housing for use in murky water and an adjustable dog added.

C. Yes. Dogs of the proper size might be desirable.

D. Add dogs at the bottom of the saw as we did. Add a quick-release trigger and maybe a safety shield that moves away from the blade as it goes into the wood.

10. Was the blade easy to change?

A. Yes.

B. Yes.

C. Yes.

D. Wing nuts could be used instead of screws to take the cover off. It is easy but time-consuming.

11. Did it stay tight in use?

A. Yes.

B. Yes.

C. Sometimes.

D. For 1/2 hour, yes. It would work loose.

12. Did the blade bind excessively in use?

A. No.

B. No.

C. Yes.

D. No.

13. Was the tool excessively fatiguing in use?

A. No.

B. No.

C. Yes.

D. Not really. The main handle could be a bit longer to gain leverage

14. Did the supply and return hoses result in any problems in using the tool?

A. No.

B. At times.

C. As much as for most hydraulic tools.

D. Yes. They are not flexible enough and affect the angle of the cut by the drag they create.

HYDRAULIC GRINDER

1. Was the tool safe to use underwater?

   A. Yes.

   B. Yes.

   C. Only as safe as the operator. With an inexperienced diver, the tool could get away from a diver and cut him or his buddy. The safety rules may be learned very readily.

   D. Yes, as a whole. If by chance you couldn't let go of the trigger, and the wheel was in contact with the body, it could be dangerous.

2. Was it necessary to use extra weight to use the tool effectively?

   A. Yes.

   B. Yes, 10 pounds extra.

   C. It would depend on the orientation of the diver to the work. With proper tethering, extra weight wouldn't be required in most instances.

   D. Extra weight is not necessary, but it helps if you can use the tethering jacket.

3. Did the tool grind rapidly enough to be effective for underwater use?

   A. Yes.

   B. Yes.

   C. I would say yes. With knowledge of what grinding wheel to use and the proper techniques, the tool could be very useful.

   D. Rapidly, yes; but power is the problem.

4. Do you believe the tool should be more powerful?

   A. Yes, enough so that the tool doesn't stall when you apply heavy pressure.

   B. No.

   C. Yes, slightly.

   D. Yes. It should be powerful enough to keep grinding with the pressure the diver can apply to it.

5. Are both hands required to use the tool?

   A. Yes.

   B. Definitely yes.

C. Definitely yes, unless a person was super strong.

D. Yes. You can't keep the tool in one spot with one hand.

6. Is tethering desirable in using the tool?

A. Yes.

B. Yes.

C. The tool would be useless unless the diver was tethered. Because of torque created by the tool and the tendency for the diver to be dragged along the work, it would be nearly impossible to work without tethering.

D. Yes, it keeps you in one place and gives you something to use leverage against.

7. Do you believe operators should receive special training in use of the tool?

A. No.

B. No.

C. Yes. As with every other power tool, proper technique for any individual can be improved with practice. There is a slow and a fast way of working with all these tools. I believe two people could expend the same energy but one produce twice the work.

D. The tool, no; but the tethering, yes.

8. Was the training you received adequate?

A. Yes.

B. Yes.

C. Yes.

D. Yes, very.

9. Do you have any design change recommendations?

A. No.

B. No.

C. The auxiliary handle, which is 90 degrees from the main handle, could be made adjustable so it could be rotated into the desired position.

9. Continued.

D. Yes. The handle design is wrong. The trigger shouldn't extend the length of the handle. The handle angle is wrong, and it makes your arm tired because of the awkward position. The handle on the side should be changed to a holding-ring-type handle on top for better positioning.

10. Was the grinding disk easy to change?

A. Yes.

B. Yes.

C. Yes, but care must be taken to ensure that the disk is properly secured. There is potential danger of the disk flying apart or off the tool.

D. Yes. Only one tool required.

11. Did it stay tight in use?

A. Yes.

B. Yes.

C. Yes.

D. Yes.

12. Did the grinding wheel grab or stall out?

A. Yes.

B. Yes.

C. Yes. With much pressure applied against the face of the disk, or when too deep a cut is made, jamming the disk, it will then stall. This I would call improper technique.

D. Yes. There was a power problem. The wheel should be tapered to grind a bevel so it won't bind.

13. Was the tool excessively fatiguing to use?

A. Yes.

B. No.

C. No. Relatively speaking, would say the fatique was mild.

D. Yes. The handle angle creates an awkward position and causes the wrist and forearm to tire.

14. Did the supply and return hoses result in any problem using the tool?

A. No.

B. No.

C. The usual. They are too stiff.

D. Yes. They are not flexible enough. They are difficult to position and often cause a balance problem.

15. Were any special techniques required to use the tool properly?

A. No.

B. No.

C. Only the techniques required in proper grinding practices.

D. No.

16. Was the staging effective in using the tool in the vertical position?

A. Yes.

B. Yes.

C. Yes and no. The platform was handy for setting up the plates and getting tethered into position, but wasn't much use while I was grinding. I braced both knees against the test plate.

D. Yes. It gave a good surface to push against and to steady yourself.

17. Did the tool have a very great tendency to impart motion to the operator?

A. No.

B. Very little.

C. The tool would drag you across the work if you weren't tethered in or weighted down.

D. Yes, when grinding flat. Perhaps a center spin could be created to offset this.

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